OPC CALIBRATION FOR PRE-PRODUCTION EUVL

IMEC CORE CMOS

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(1) MENTOR GRAPHICS

(2) IMEC

OUTLINE

- Introduction
- NXE:3100 OPC modeling
  - Mask
  - Structure Selection
  - Exposure and Metrology
  - Modeling
  - EUV Model Calibration
  - EUV Model Validation
- Conclusions

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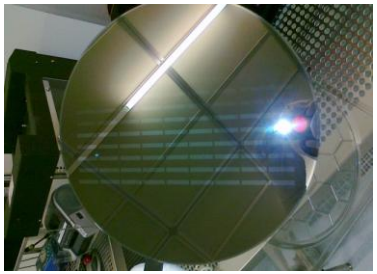
INTRODUCTION

NXE:3100 at imec

- Field size: 26x33mm^2
- NA=0.25 and σ=0.81
- 6 off-axis illumination conditions available
- Flare < 8%
- Interfaced to TEL Lithius Pro for EUV
- XTREME DPP source



First wafer at imec on May 2nd, 2011

- Goal:
  - EUV OPC on NXE:3100 for 27nm CH with RMS < 1.5nm

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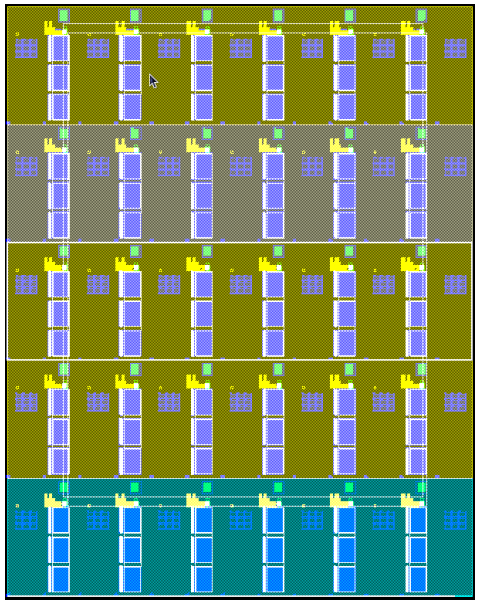
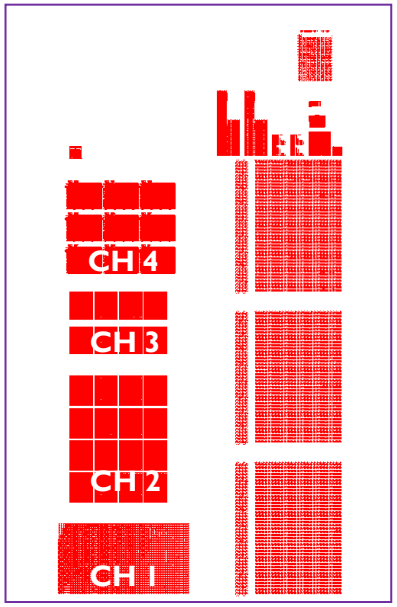
NXE-3100 OPC CH LAYOUT

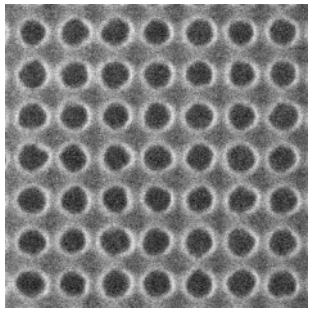
Layout



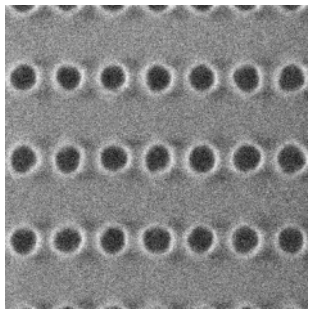
Basic Cell



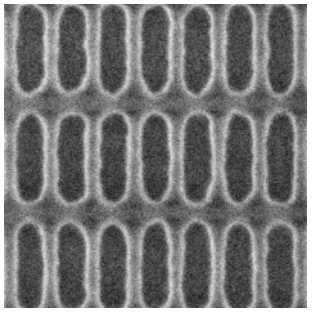
CH 1 Square CH



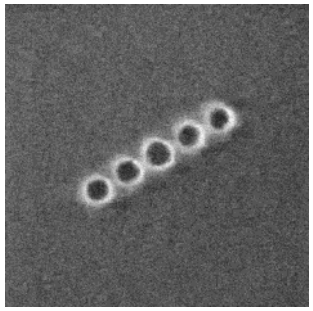
CH 2 Pitch X ≠ Y

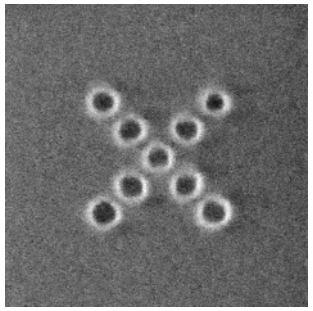


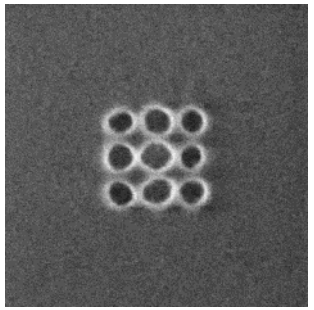
CH 3 CD X ≠ Y



CH 4 Different Geometries





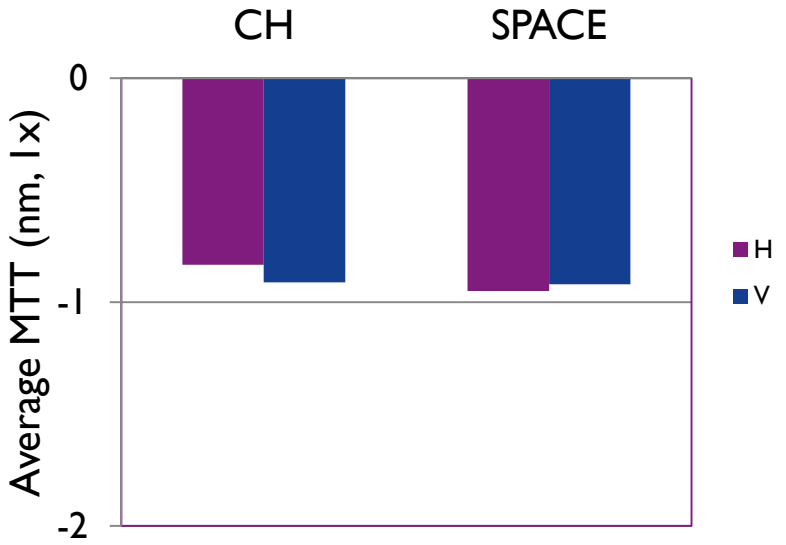


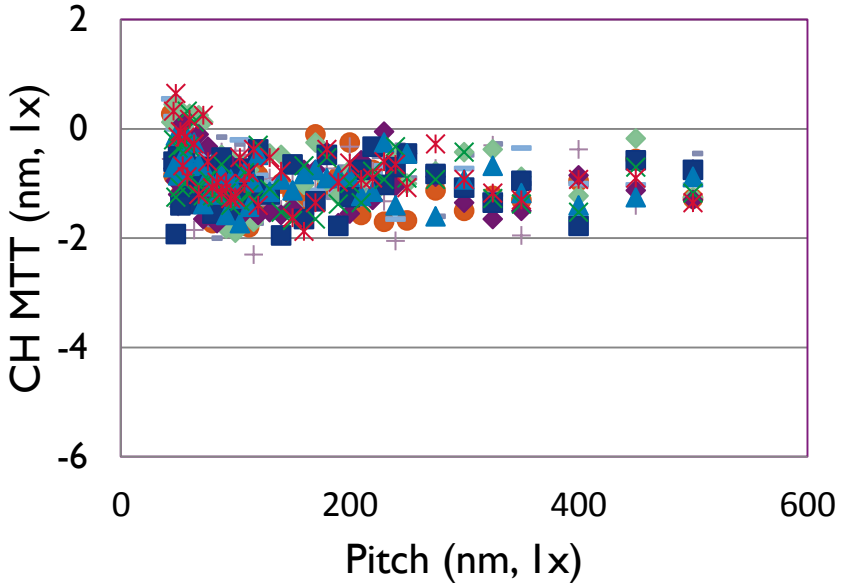
- Flare Modulation (scan)
- Smallest Pitch 32nm
- Smallest CD 10nm
- Smallest step 0.25nm

• All 4 different 2D sub-modules used in the OPC exercise

CH MASK METROLOGY

- ~ 1300 measurements on mask





- Average MTT ~ -1nm (1x) for CH and Space H and V
- Small CH mask proximity signature range ~1.23nm (1x)
- CDU ~ 1.6nm (1x) for 32nm dense CH

•The mask process is suitable for the OPC exercise in the range of interest

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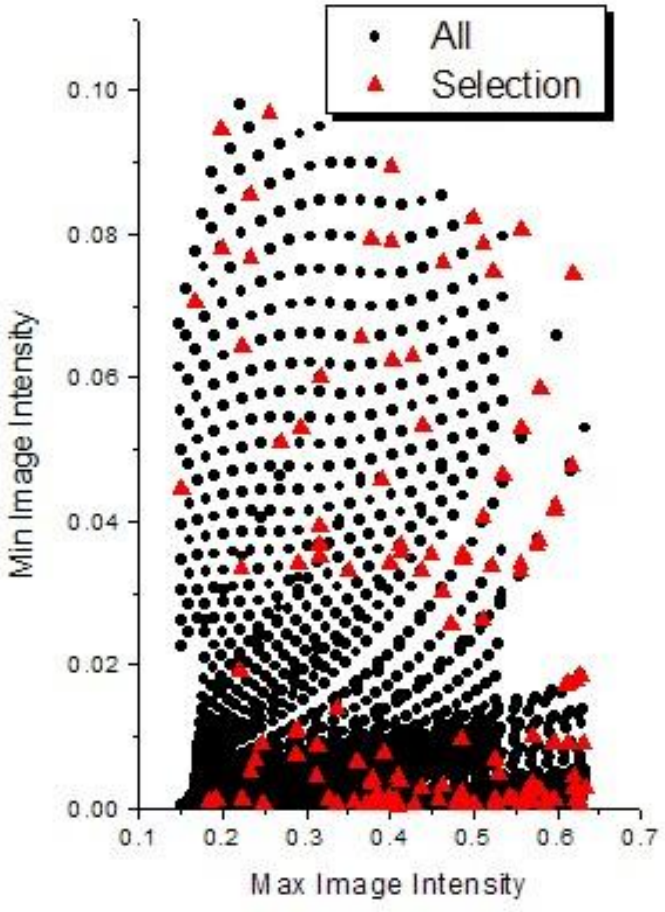
STRUCTURE SELECTION FOR MODEL CALIBRATION

- **Goals:**
  - Defining a set of structures representing the entire modeling space
  - Minimize wafer metrology
- **Methodology:**
  - Sampling in 5D aerial image parameter space
- **Feature Set**

Module	Feature Type	Gauges #
CH 1	Square	84
CH 2	Pitch X ≠ Y	162
CH 3	CD X ≠ Y	104
CH 1	Square	496
CH 4	Different Geometries	48

Calibration (center and top scan)
Verification (through slit and scan)



A. Abdo, et al, Proc SPIE 7640, 76401E, 2010

• Calibration set of 350 gauges defined by optimized sampling in image-parameter space

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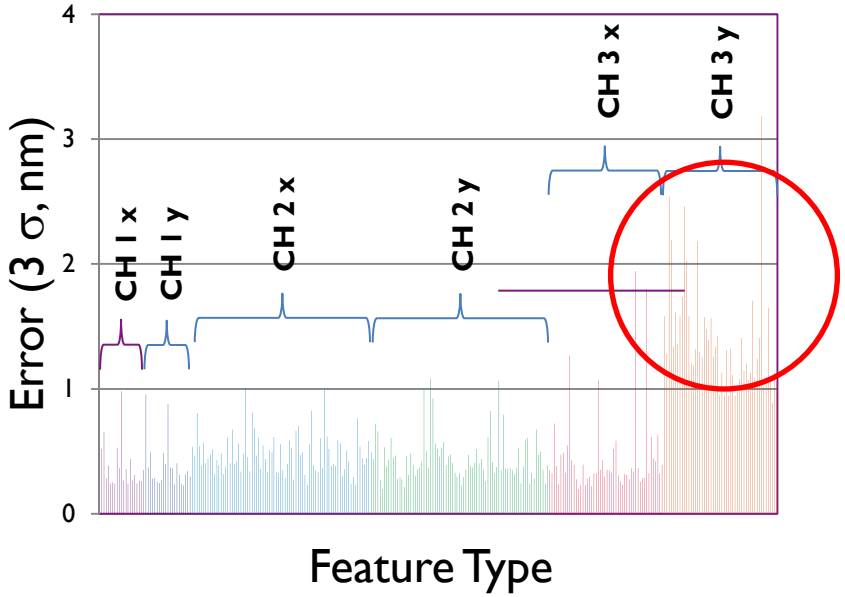
EXPOSURES AND METROLOGY

Exposures

- **Exposure Tool**
  - NXE:3100
  - NA = 0.25, σ = 0.81Conventional
- **Resist**
  - Shin-Etsu SEVR140 50nm thick
- **FEM**
  - NE = 19mJ/cm^{2,} ; DE =1mJ/cm^2
  - NF =0.00μm ; DF =0.04μm
  - Dose / Focus steps 11x9
- **CDU**
  - NE = 19mJ/cm^{2,} ; NF =0.00μm
  - 71 fields

Metrology

- CD SEM: Hitachi CG 4000
- Design Gauge
- Algorithms: Ellipse, Gap
- Both algorithms less precise and accurate for elongated CH (CH 3)
- New Gap algorithm (Sector) shows better precision



• Target 27nm Dense CH 20% bias with conventional Illumination

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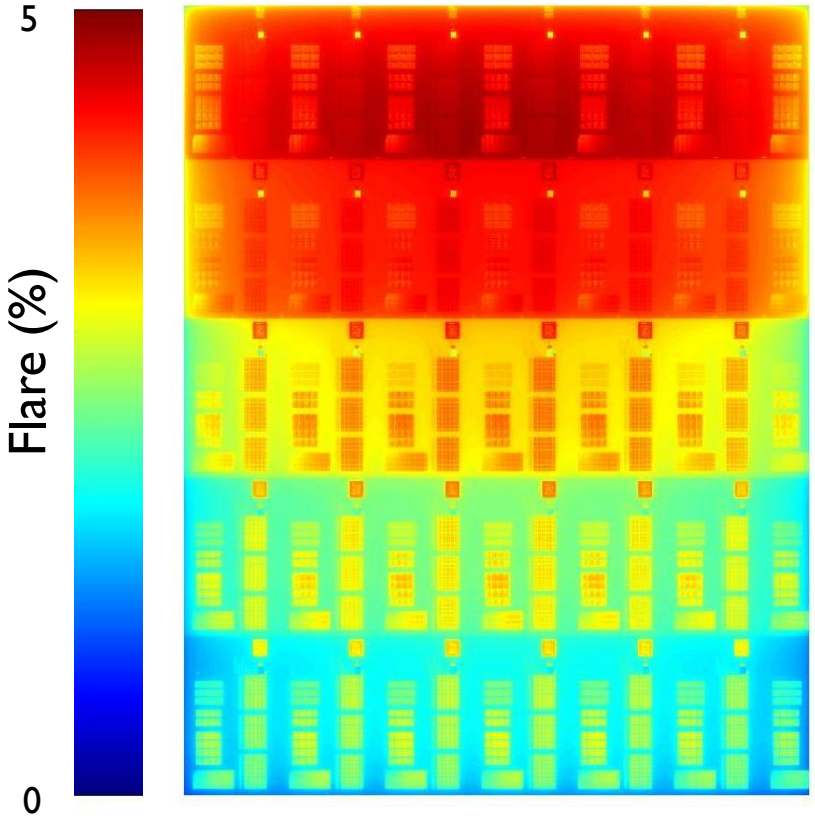
MODELING

- **Target**
  - 27nm dense CH (20% mask bias)
- **Resist Model**
  - Different Gaussian diffusion image terms optimized during regression (Mentor Model Form 21)
- **Shadowing**

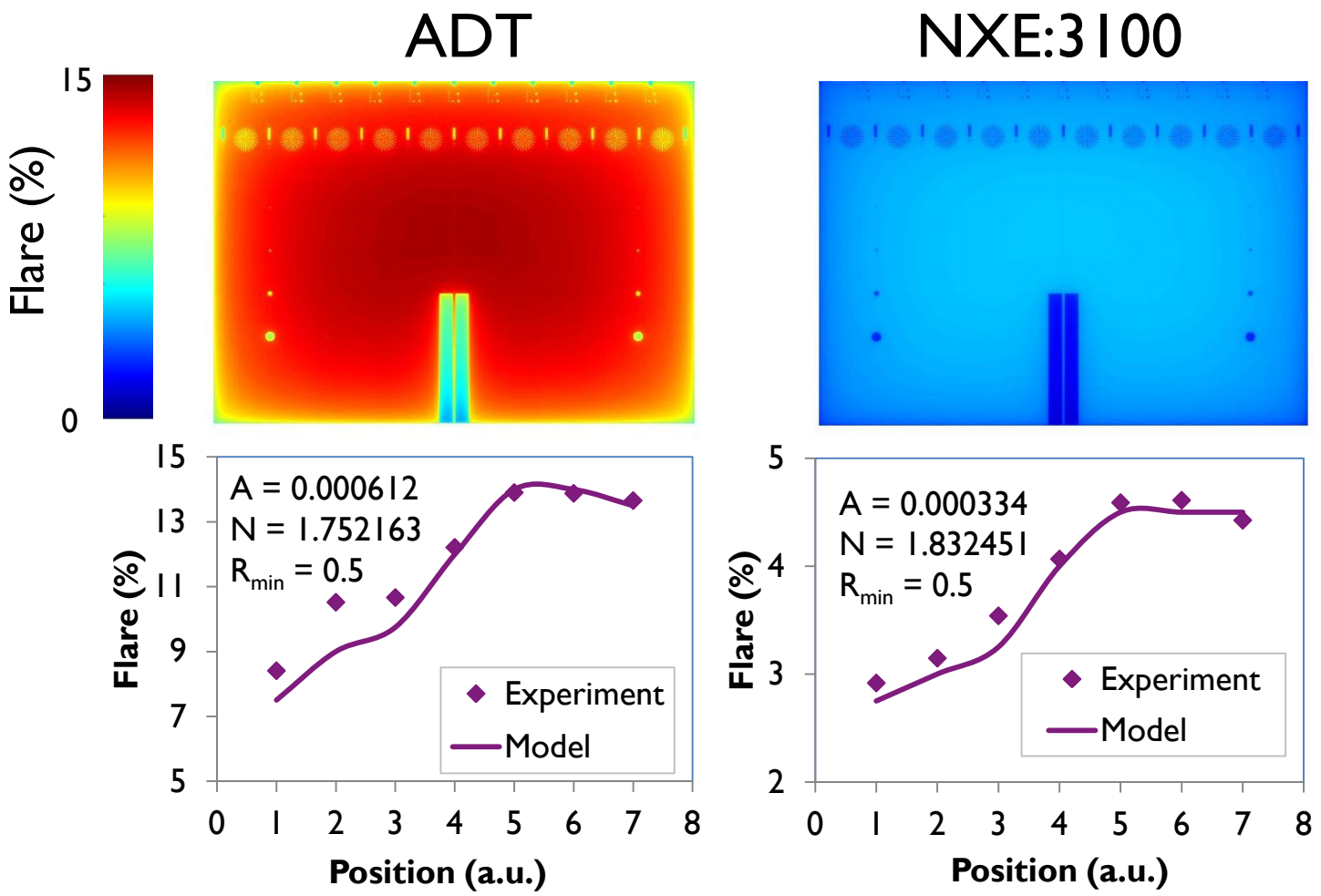
  Domain Decomposition Method (DDM)
  - Model calibration in slit center (image plane position, grid size,...)
  - Separate DDM libraries dedicated to each slit location to model shadowing through slit
- **Flare**
  - Single fractal PSF fitted to flare wafer data for imec NXE:3100 (Kirk pads)
  - PSF = A $(r)^{-N}$ [$r > R_{min}$]



Total of 894 gauges used for validation and verification

GF Lorusso, et al, JM3 (2009)

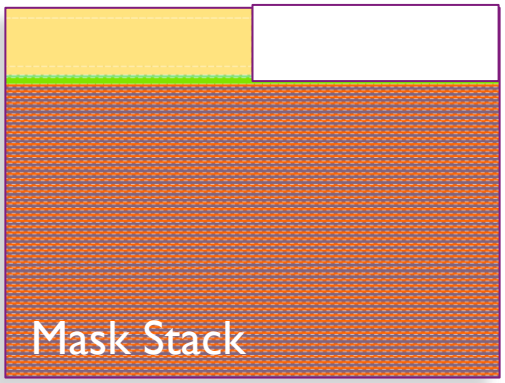
FLARE MODELING

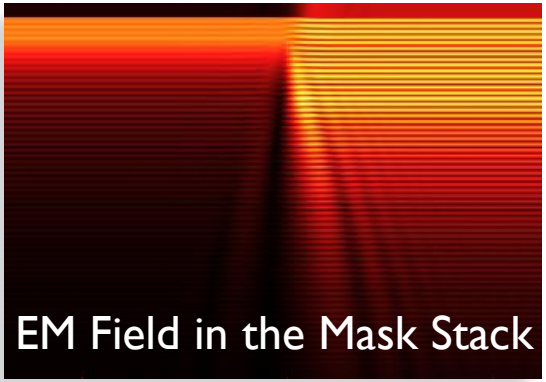


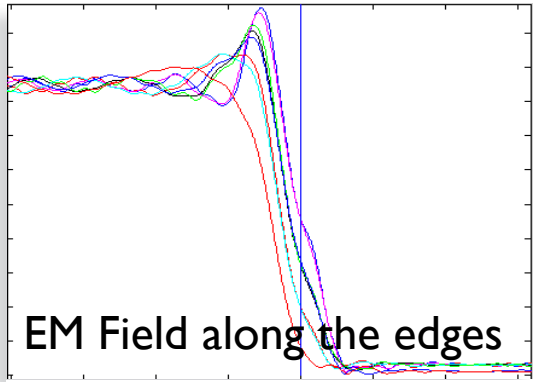
Flare modeling matches well with wafer data

3D EUV MASK OPTICAL MODELING

Fast 3D mask topography modeling with off-axis incidence & azimuthal angle using Domain Decomposition Method (DDM).

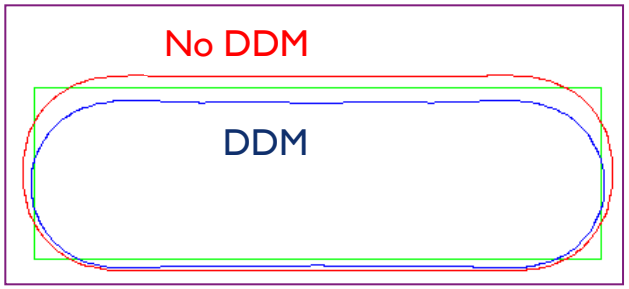






DDM library with signals for various edge orientations settings of (θ, ϕ, polarization)

- 3D EUV Mask simulator against a 3rd-party FDTD simulator from Panoramic
- Generally very good agreement for features > 20nm.



Mask shadowing captured by DDM

Optical Simulation Engine

Separate DDM signals are added on each edge to create the 3D mask reflection

DDM accounts for shadowing based on a rigorous optical physical model

Word J. *et al*, "*EUV Lithography Challenges for Computational Lithography*", . (BACUS 2011)

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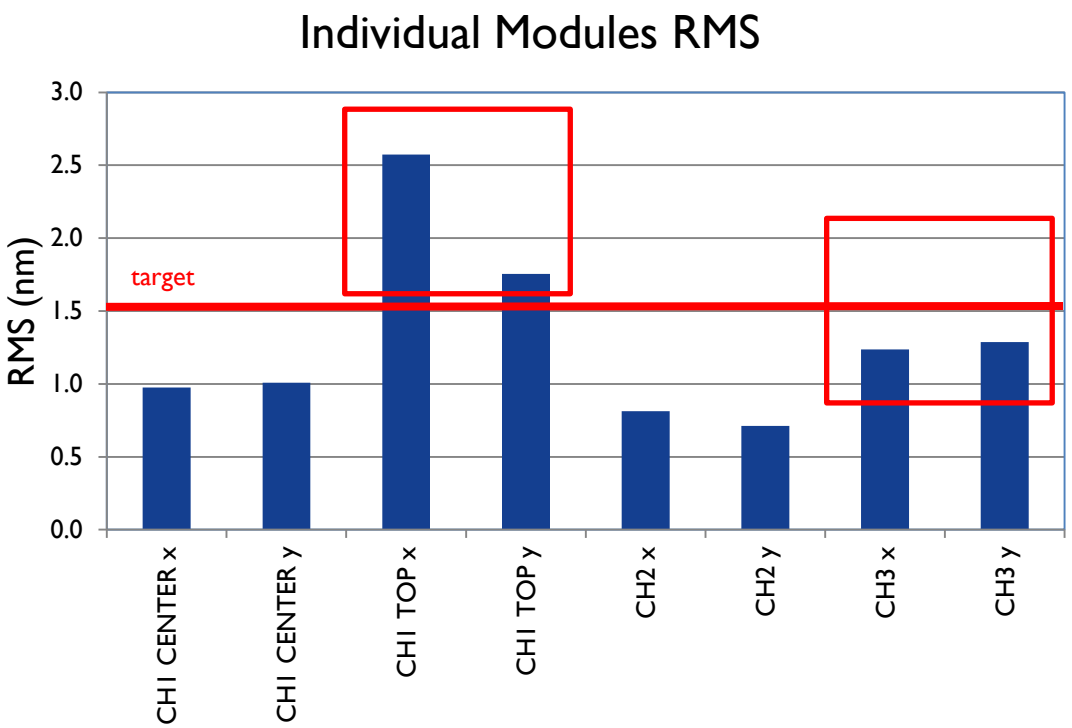
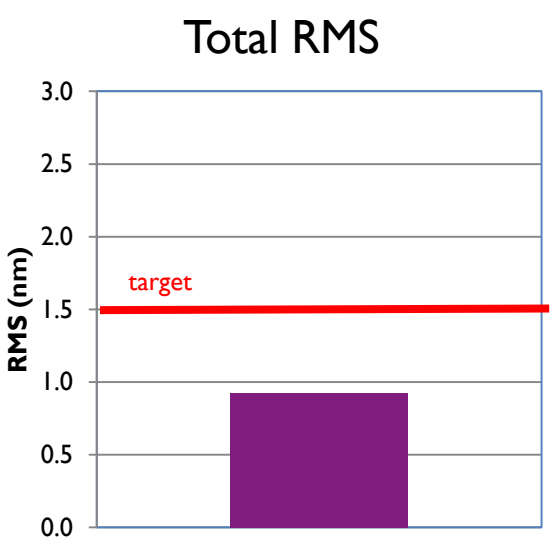
MODEL CALIBRATION

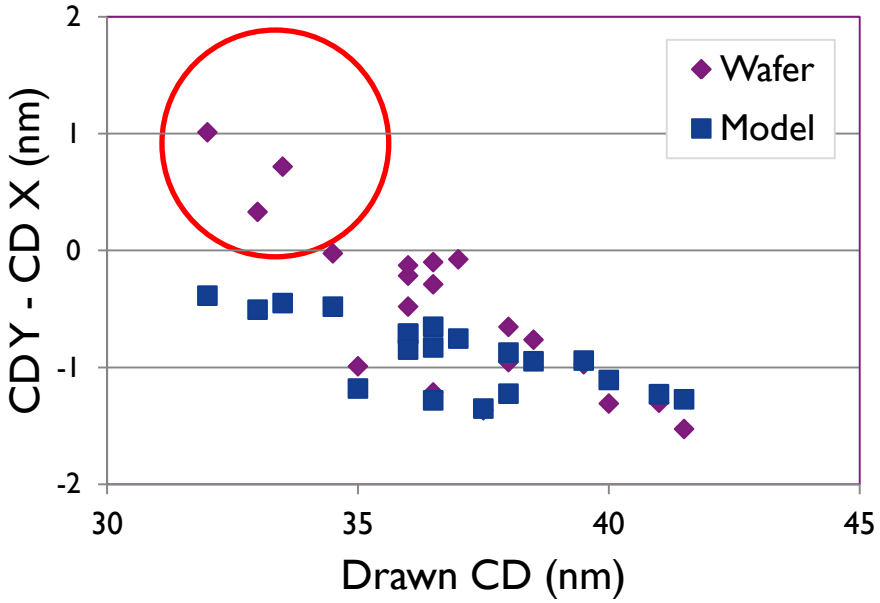




- Larger errors for elongated CH (CH 3) caused by metrology
- Larger error for Top Module caused by the CD variation on mask
  → Lower weights for CH 1 Top (0.1 x and y) and CH 3 (0.5 x and 0.1 y)

- Model calibration RMS 0.92nm < 1.5

SHADOWING IN MODEL CALIBRATION

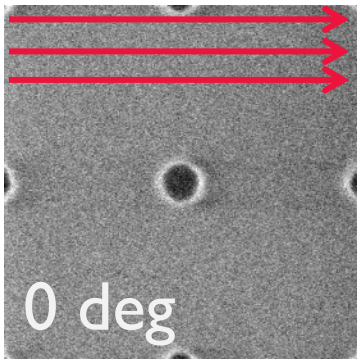


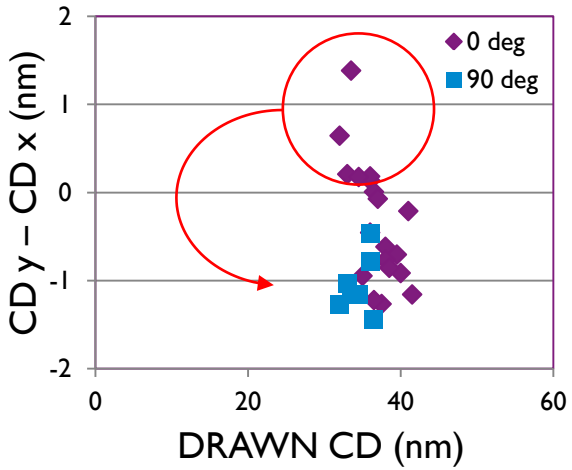
- Shadowing modeling deviates from experiment for small CD
- Simulation including system aberration did not reduce the effect

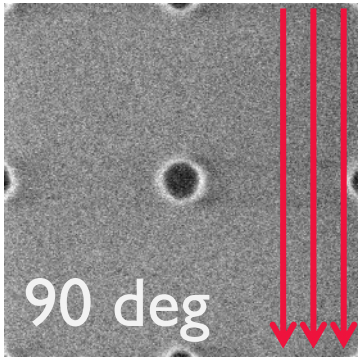
- Shadowing model differs from experiment for small CD

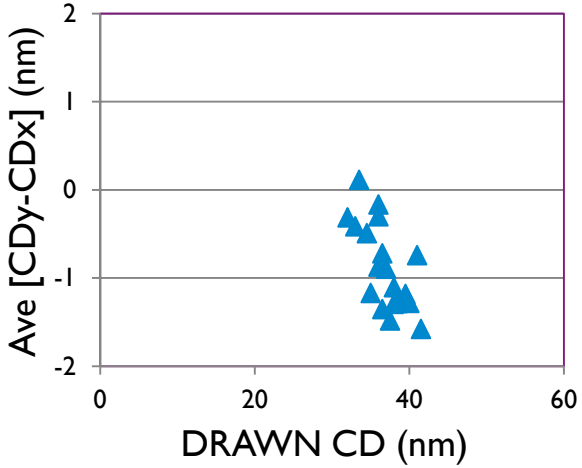
GF Lorusso, et al, SPIE (2012)

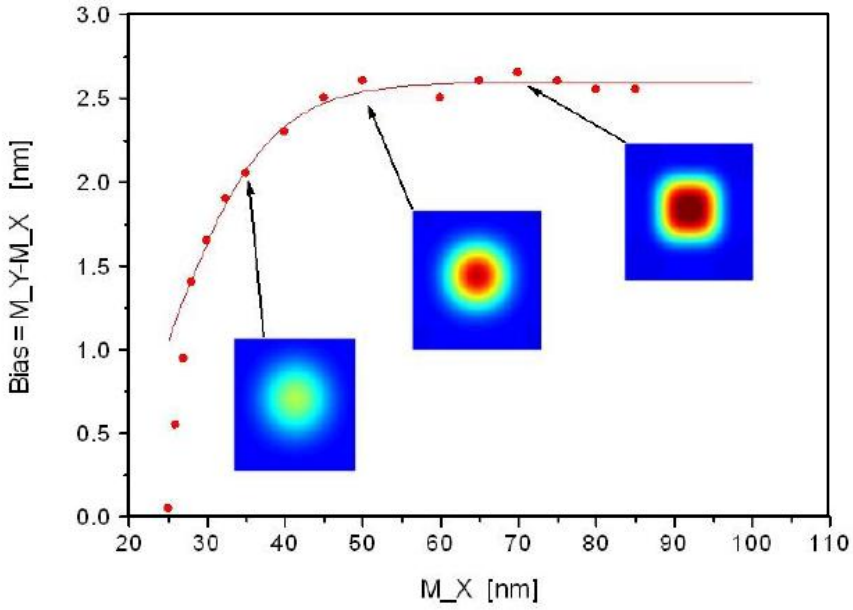
IMPACT OF SEM METROLOGY











- Shadowing > 0 is a SEM artifact
- Average on scan removes the artifact
- Results consistent with simulations

- The experimental deviation from the model is a SEM artifact
- Shadowing effect marginal for small CH as expected

L Grella, GF Lorusso, et al, Scanning 25, 175 (2003)

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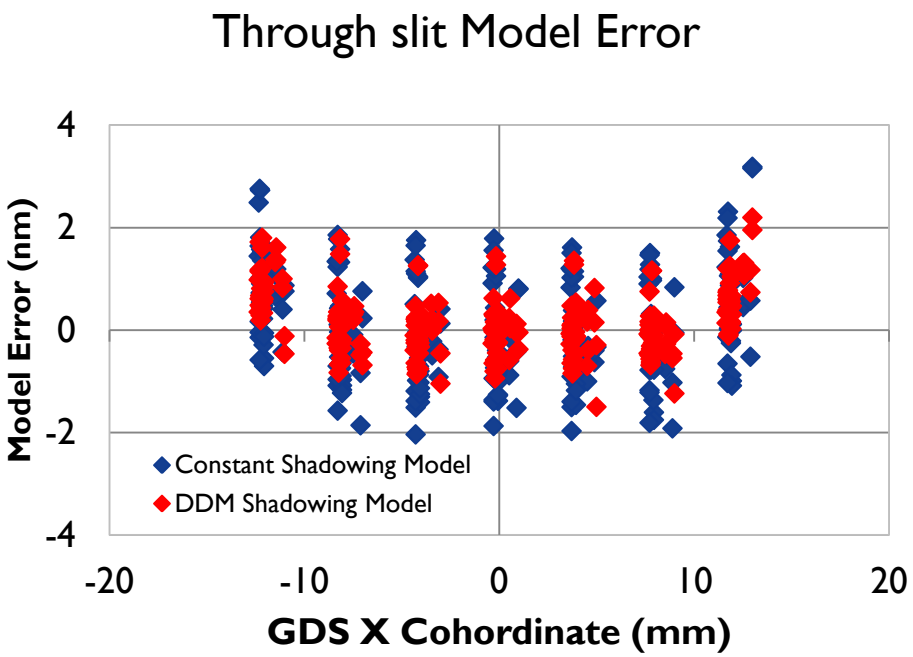
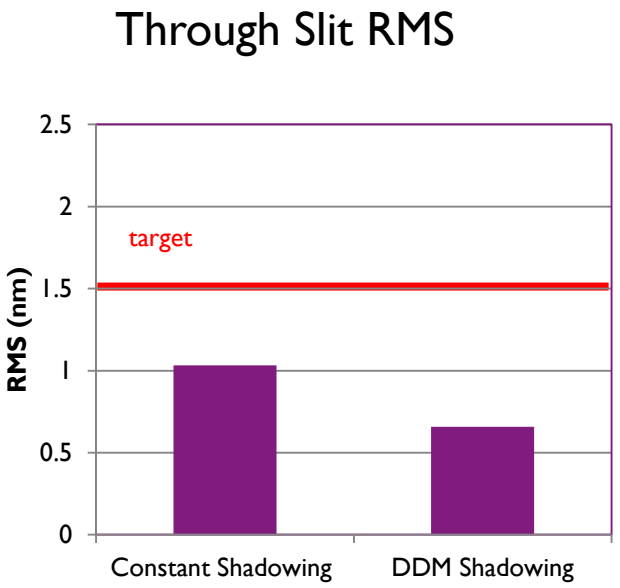
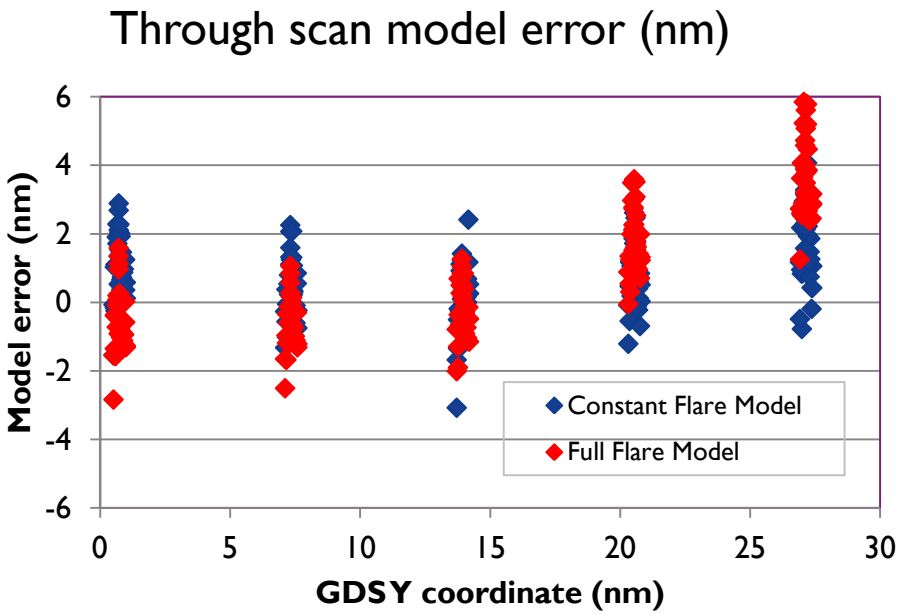
MODEL VALIDATION THROUGH SLIT

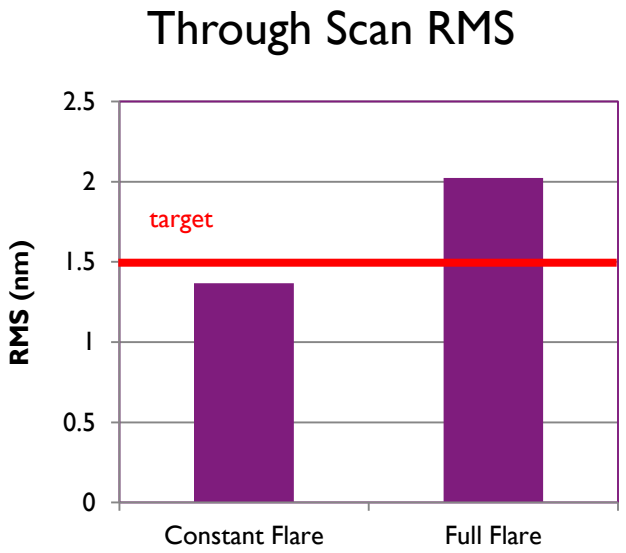




- Simplified Model verification through slit RMS 1.03nm < 1.5nm
- DDM Model verification through slit RMS 0.65nm

MODEL VALIDATION THROUGH SCAN





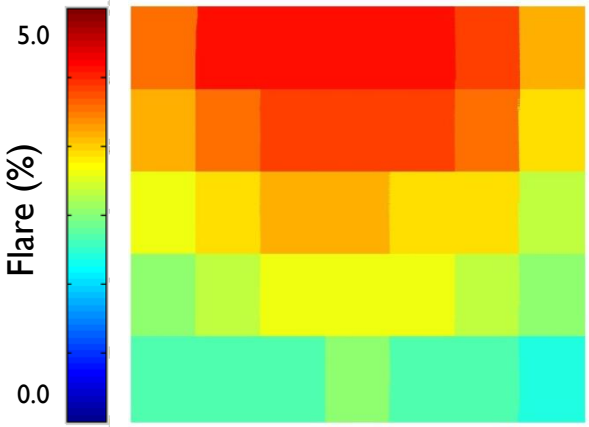
- Error changes across field
- Trend through scan confirmed on multiple wafers

- RMS 2.02nm > 1.5nm

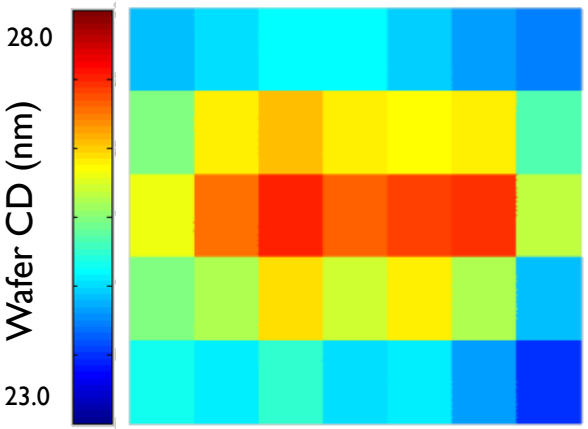
MODEL VALIDATION THROUGH SCAN

32nm Dense CH across die

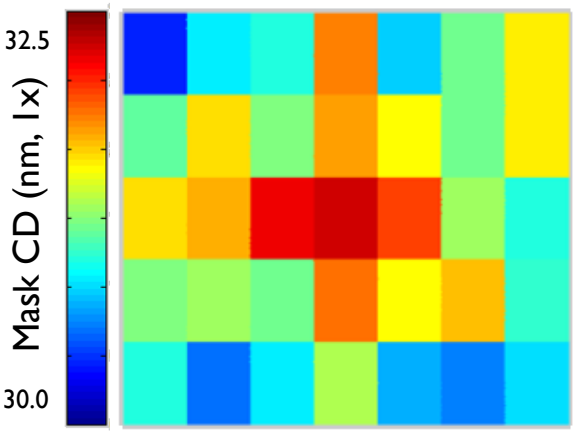
FLARE



WAFER



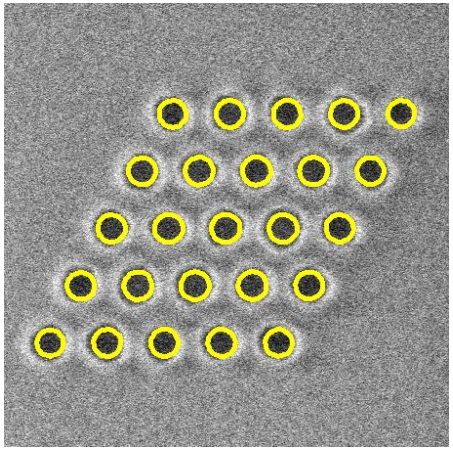
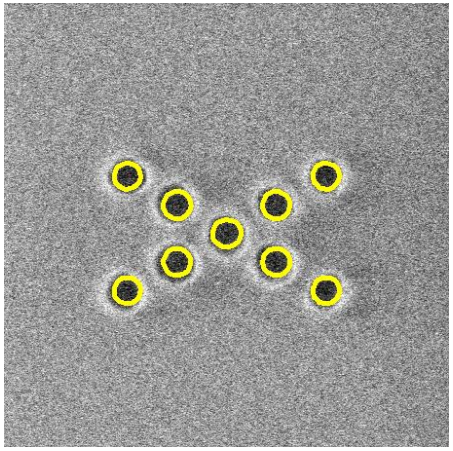
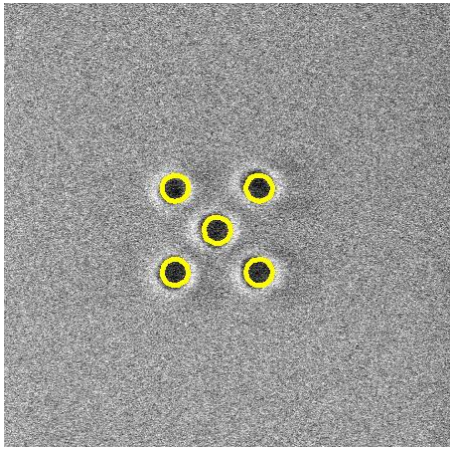
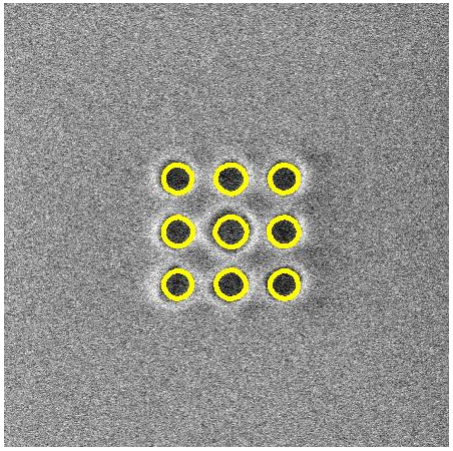
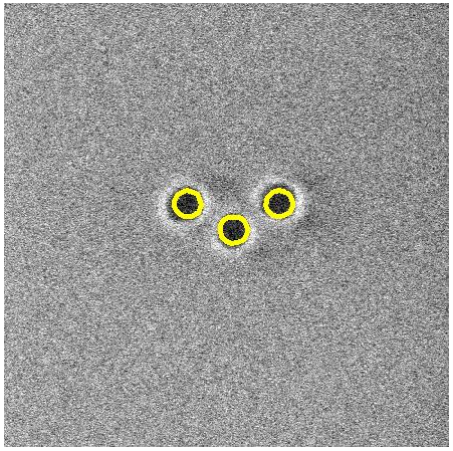
MASK



- Wafer CD does not show expected flare trend
- Wafer CD agrees with mask signature

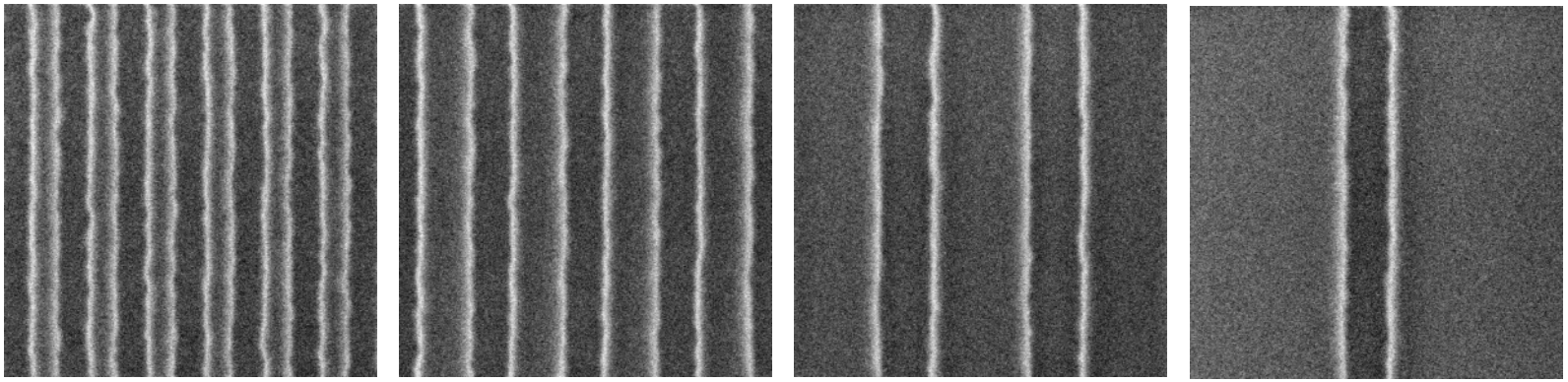
- The wafer signature is dominated by the mask signature

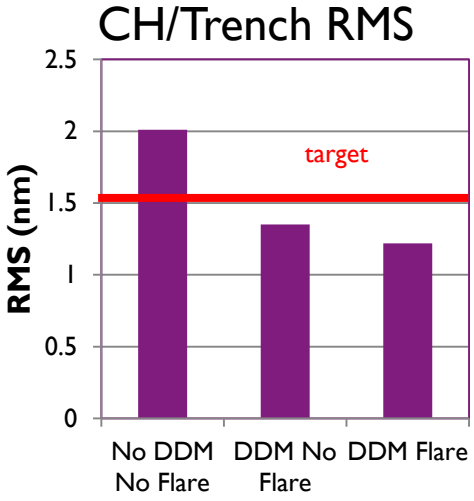
MODEL CONTOUR VALIDATION

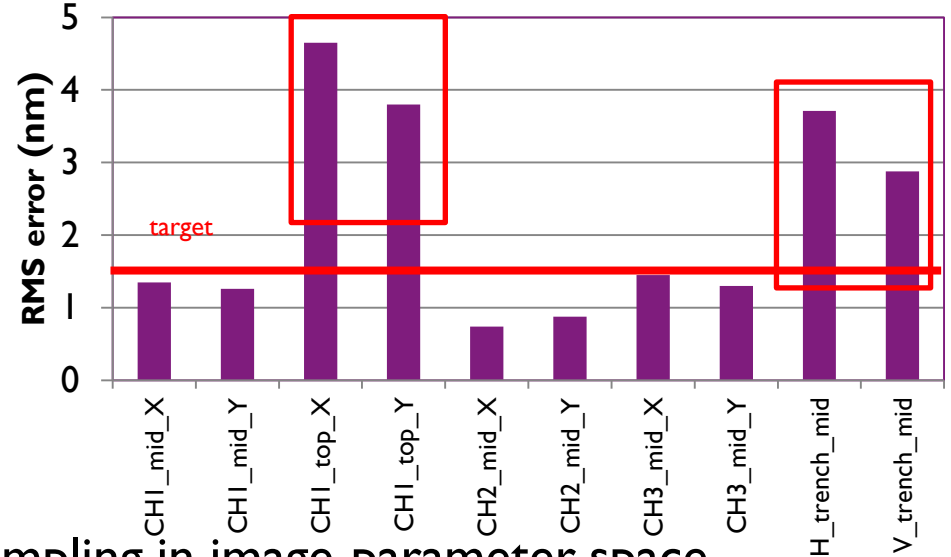






• Nice agreement between predicted contours and wafer images for CH 4

MODEL CALIBRATION WITH CH AND TRENCH







- Trench set selected by sampling in image-parameter space
- Smallest trench CD on wafer ~ 32nm
- Larger RMS for trench possibly caused by difference in metrology

- RMS 1.22nm

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CONCLUSIONS

- An EUV modeling exercise targeting 27nm Dense CH has been preformed on NXE:3100 using conventional illumination targeting an RMS < 1.5nm.
- The mask used in this exercise has been characterized (~1300 mask measurements), and demonstrated good MTT (~ -1nm) and CDU (~1.6nm).
- A total set of 894 gauges has been selected for calibration and validation by appropriate sampling of the parameter space.

	RMS (nm)	
Calibration CH	0.92	<1.5
Verification Through Slit	0.65	<1.5
Verification Through Scan	2.02	>1.5
Calibration CH -Trench	1.22	<1.5

- The verification through scan yielded a larger RMS > 1.5nm caused bt the mask signature.
- The modeled contours were found in good agreement with the wafer results.
- The discrepancy observed between modeling and wafer data for CH shadowing was caused by a SEM metrology artifact.
- We observed that small CH are less sensitive to shadowing.

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We wish to thanks all the many people that contributed in a critical way to this study, in particular:

- Imec
  - Darko Trivkovic, Rudi De Ruyter, Jan Hermans, Philippe Foubert
- Hitachi
  - Toru Ishimoto, Kohei Sekiguchi, Daisuke Fuchimoto
- ASML
  - Andre Van Dijk, Eelco van Setten, Kees Feenstra, Stuart Young

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